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RESEARCH MEMORANDUM

WIND-TUNNEL INVESTIGATION OF THE EFFECTS OF VARIOUS DORSAL-FIN AND VERTICAL-TAIL CONFIGURATIONS ON THE DIRECTIONAL STABILITY OF A STREAMLINED BODY AT TRANSONIC SPEEDS

TRANSONIC-BUMP METHOD

By Harold S. Johnson and William C. Hayes

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation was made in the Langley high-speed 7- by 10-foot tunnel to determine the effects of various dorsal-fin and vertical-tail configurations on the directional stability characteristics of a streamlined body through a Mach number range of 0.59 to 1.11. The model was sting-mounted in the high-velocity flow field generated over the curved surface of a bump located on the tunnel floor.

The results of the investigation indicated that, for angles of sideslip greater than about 10°, the addition to the body of dorsal fins having a local projection equal to 10 percent of the maximum diameter of the body and located on the rear 31.6 percent of the body was very effective in improving the directional stability characteristics of the body alone throughout the Mach number range investigated. For angles of sideslip greater than about 10°, the addition to the vertical-tail—body combination of either of two dorsal fins (differing in plan form) extending forward from the leading edge of the vertical tail resulted in improvements in the directional stability characteristics of the vertical-tail—body combination.

The addition to the body of either a tapered low-aspect-ratio vertical tail or a ring tail having a diameter equal to the span of the vertical tail provided sufficient yawing moment to overcome the adverse moments of the body alone. The stability was greater at small angles of sideslip and the yawing moments were less at large angles of sideslip for the body with the ring tail than for the body with the tapered low-aspect-ratio vertical tail. At small angles of sideslip, the stability of the vertical-tail—body configuration decreased with increasing Mach number below a Mach number of approximately 1.03 and became marginal at a Mach number of approximately 1.03.

INTRODUCTION

The current use of external stores, missiles, and low-drag bombs at high transonic and supersonic speeds has created a need for information on the release and stability characteristics of fin-stabilized bodies. In order to facilitate storing and handling of these bodies, the tail span and, consequently, the tail area has been kept to a minimum. One design criterion currently being considered is to limit the tail span to the diagonal of a square having sides equal to the maximum diameter of the body. Therefore, for some configurations, it is difficult to obtain adequate stability throughout an angle-of-pitch or sideslip range. The use of zero-length launchers and the release of bodies in the turbulent-flow field around an airplane or from a bomb bay sometimes result in initial flight attitudes having large angles of pitch or sideslip.

Dorsal fins have been widely used to improve the directional stability characteristics of aircraft. Although the use of dorsal fins sometimes improves the stability in the vicinity of zero sideslip, they are primarily used to maintain stability to the higher angles of sideslip where the vertical-tail surfaces lose effectiveness.

The present investigation, which was made in the Langley high-speed 7- by 10-foot tunnel, has been undertaken to extend the available information on dorsal fins (for example, ref. 1) to the transonic speed range as well as to present directional stability characteristics of a streamlined body having various vertical-tail configurations through a large angle of sideslip range.

SYMBOLS

C_n yawing-moment coefficient, $\frac{N}{qSl}$

N yawing moment about center of gravity, ft-lb

q effective dynamic pressure over length of model, $\frac{\rho V^2}{2}$, lb/sq ft

S maximum cross-sectional area of body, sq ft

l theoretical length of body, ft

D_{max} maximum diameter of body, ft

c local chord of tail, ft

ρ mass density of air, slugs/cu ft

V free-stream velocity, ft/sec

M effective Mach number over length of body

R Reynolds number of body based on l

β angle of sideslip, deg

$C_{n_\beta} = \frac{\partial C_n}{\partial \beta}$ at $\beta = 0^\circ$

MODEL AND APPARATUS

The body ordinates were basically those of the Douglas Aircraft Company, Inc., store shape (table I). The rear portion of the body was modified to accommodate a sting balance (fig. 1). This modification consisted in cutting off the rear 3.24 percent of the body, increasing the diameter at this station, and refairing the body contour with straight-line elements which became tangent to the original contour at about the 77.5-percent station. The various configurations investigated are shown in figure 1. Dorsal fin A had a beveled cross section, local projection of 10 percent of the maximum diameter of the body, and extended over the rear 31.6 percent of the model length. The vertical tail of aspect ratio 1.60 and taper ratio 0.43 was a flat plate with beveled leading and trailing edges. The maximum thickness ratio was 0.05 and the sweepback of the leading edge was 45°. The vertical-tail span was equal to the diagonal of a square having sides equal to the maximum diameter of the body. The body plus vertical-tail configuration was similar to a 1000-pound low-drag bomb with a modified afterbody and with the horizontal surfaces of the cruciform tail omitted. Dorsal fin B was the forward portion of dorsal fin A. Dorsal fin C had a beveled cross section and a constant span equal to the maximum diameter of the body. The leading edge of each dorsal fin was located at approximately the afterbody junction station of the prototype bomb. The ring tail had an inside diameter equal to the span of the vertical tail, a chord equal to the tip chord of the vertical tail, and a constant 5-percent-thick section with a radius leading edge and a beveled trailing edge. This ring tail would not fit within a square having sides equal to the maximum diameter of the body. The ring tail was attached to the tips of the vertical tail and the model was rotated 90° about the longitudinal axis so that the vertical tail became a horizontal-tail surface and was alined with the air stream throughout the angle-of-sideslip range.

The model was tested on the sting-support system shown in figure 2 and could be remotely operated through an angle-of-sideslip range from -2° to 60°. A one-component electrical strain-gage balance which measured the model yawing moment was contained within the body. The yawing moments were recorded by means of a calibrated potentiometer. The model was located 8 inches above the surface of a transonic bump. The sting support was attached to a five-component strain-gage balance located below the bump surface. The slot in the bump surface which allowed the sting support to traverse through the angle-of-sideslip range was sealed by a sliding cover plate. (See fig. 2.)

TESTS AND CORRECTIONS

The tests were made in the Langley high-speed 7- by 10-foot tunnel by utilizing the transonic-bump technique. This technique involved mounting the model in the high-velocity flow field generated over the curved surface of a bump located on the tunnel floor. Local Mach numbers were obtained at four stations on the model center line with the sting support in position and with the model replaced by a 1/4-inch diameter probe. The test Mach number was considered to be the average of the four local Mach numbers. The maximum variation in Mach number over the length of the model was about 0.004 at a Mach number of about 0.6 and about 0.05 at a Mach number of about 1.11.

The variation of Reynolds number with Mach number for typical test conditions is presented in figure 3. The Reynolds numbers were based on the theoretical length of the body, 0.833 foot. Yawing moments were obtained through a Mach number range from 0.59 to 1.11 for an angle-of-sideslip range from -2° to 60° except for some configurations when the angle-of-sideslip range was limited by model load, fouling, or extreme vibration.

The angles of sideslip have been corrected for the deflection of the sting and sting support under load. These corrections were determined by a static calibration with the model and sting support loaded in order to duplicate the measured moment on the model and the forces and moments on the sting support which were obtained from the five-component balance located beneath the bump surface. The maximum correction for the extreme loading conditions which occurred at the highest angles of sideslip was about 5°.

RESULTS AND DISCUSSION

The variation of yawing-moment coefficient with angle of sideslip for the various Mach numbers is presented in figures 4 to 9 for the six configurations investigated. The variation of the parameter C_{n_β} with Mach number is presented in figure 10. In figure 11 the data from figures 4 to 9 are summarized to show the effect of model configuration on the variation of C_n with β for Mach numbers of 0.79, 0.93, and 1.03.

For angles of sideslip of less than about 25°, the body-alone configuration was unstable and the variation of C_n with β was relatively unaffected by Mach number variations (figs. 4 and 10). The yawing moments were negative throughout the positive angle-of-sideslip range.

For the Mach number and angle-of-sideslip ranges investigated, the data of figures 5, 10, and 11 show that the directional stability characteristics of the body were improved by the addition of dorsal A. The instability of the body-alone configuration was reduced by about 21 percent for angles of sideslip near 0°. For angles of sideslip greater than about 10°, the addition of dorsal A markedly reduced or, for some angles of sideslip and Mach numbers, eliminated the negative body yawing moments.

The addition of the vertical tail provided sufficient yawing moment to overcome the adverse body moments for the test Mach number and angle-of-sideslip ranges (figs. 6 and 11). This body—vertical-tail configuration was stable for angles of sidelip of less than about 48° at $M = 0.59$, and the data indicated that, for Mach numbers less than about 1.00, there was a tendency for this stable range to be reduced as the Mach number was increased. The stability at $\beta = 0^\circ$ was unaffected by Mach number variations below $M \approx 0.9$ but decreased with further increases in Mach number to $M \approx 1.03$ where the stability was marginal (fig. 10). The stability increased as the Mach number was further increased and at the highest test Mach number the stability was about equal to that for subsonic Mach numbers.

For angles of sideslip greater than about 10°, the addition of either dorsal B or C to the body—vertical-tail configuration resulted in pronounced increases in both the stability and the positive yawing moments (figs. 7, 8, and 11). The yawing moments were larger for the vertical-tail—dorsal-C configuration than for the vertical-tail—dorsal-B configuration for angles of sideslip greater than 5°. However, the stability at $\beta = 0^\circ$ was relatively unaffected by the addition of dorsal B and was reduced by the addition of dorsal C. This latter configuration was unstable for Mach numbers from 1.00 to 1.05 (fig. 10).

This decrease in stability with the addition of dorsal C to the vertical-tail—body combination is attributed to a reduction in both the effective aspect ratio and the moment arm of the dorsal-C—vertical-tail combination.

For angles of sideslip of less than about 10°, the most stable configuration investigated was the body with the ring tail (figs. 9 to 11). The parameter $C_{n_{\beta}}$ increased rapidly with increases in Mach number from about 0.86 to 1.00, whereas the body—vertical-tail configuration exhibited a marked loss in stability for this Mach number range. The stability of the ring-tail configuration decreased rapidly with increasing β above $\beta \approx 10^{\circ}$, and the yawing moments were much smaller for this configuration than for the vertical-tail configuration at large angles of sidelip.

The usefulness of ring tails may be limited by higher drag of such installations. For example, the data of references 2 and 3 show that at supersonic speeds the drag coefficients of the ring tails investigated are considerably higher than those of the cruciform-tail surfaces.

CONCLUSIONS

The results of the investigation of a streamlined body in combination with various dorsal-fin and vertical-tail configurations indicated the following conclusions:

1. For angles of sideslip greater than about 10°, dorsal fins having a local projection equal to 10 percent of the maximum diameter of the body and located on the rear 31.6 percent of the body were very effective in improving the directional stability characteristics of the body throughout the Mach number range investigated.

2. The addition of either of two dorsal fins (differing in plan form) extending forward from the leading edge of a vertical tail resulted in improvements in the directional stability characteristics of the vertical-tail—body combination for angles of sideslip greater than about 10°.

3. The addition of either a tapered low-aspect-ratio vertical tail or a ring tail having a diameter equal to the span of the vertical tail provided sufficient yawing moment to overcome the adverse body moments. The stability was greater at small angles of sideslip and the yawing moments were less at large angles of sideslip for the body with the ring tail than for the body with the tapered low-aspect-ratio vertical

tail. At small angles of sideslip, the stability of the vertical-tail—body configuration decreased with increasing Mach number below a Mach number of approximately 1.03 and became marginal at a Mach number of approximately 1.03.

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REFERENCES

1. Hoggard, H. Page, Jr.: Wind-Tunnel Investigation of Fuselage Stability in Yaw With Various Arrangements of Fins. NACA TN 785, 1940.

2. Rainey, Robert W.: Langley 9-Inch Supersonic Tunnel Tests of Several Modifications of a Supersonic Missile Having Tandem Cruciform Lifting Surfaces - Three-Component Data Results of Models Having Ratios of Wing Span to Tail Span Equal to and Less Than 1 and Some Static Rolling-Moment Data. NACA RM L50G07, 1951.

3. Grigsby, Carl E.: Tests at Mach Number 1.62 of a Series of Missile Configurations Having Tandem Cruciform Lifting Surfaces. NACA RM L51J15, 1952.

TABLE I

ORDINATES OF THE DOUGLAS AIRCRAFT COMPANY, INC., STORE SHAPE

Ordinates, percent length			
Station	Radius	Station	Radius
0	0	58.06	5.646
1.94	.946	60.83	5.507
4.72	2.033	63.61	5.332
7.50	2.869	66.39	5.125
10.28	3.513	69.17	4.888
13.06	4.016	71.94	4.623
15.83	4.416	74.72	4.334
18.61	4.745	77.50	4.023
21.39	5.026	80.28	3.693
24.17	5.272	83.06	3.347
26.94	5.485	85.83	2.989
29.72	5.661	88.61	2.621
32.50	5.785	91.39	2.246
35.28	5.833	93.61	1.944
42.50	5.833	95.83	1.630
49.72	5.833	98.06	1.208
52.50	5.812	100.00	0
55.28	5.749		
L.E. radius = 0.83		T.E. radius = 0.55	

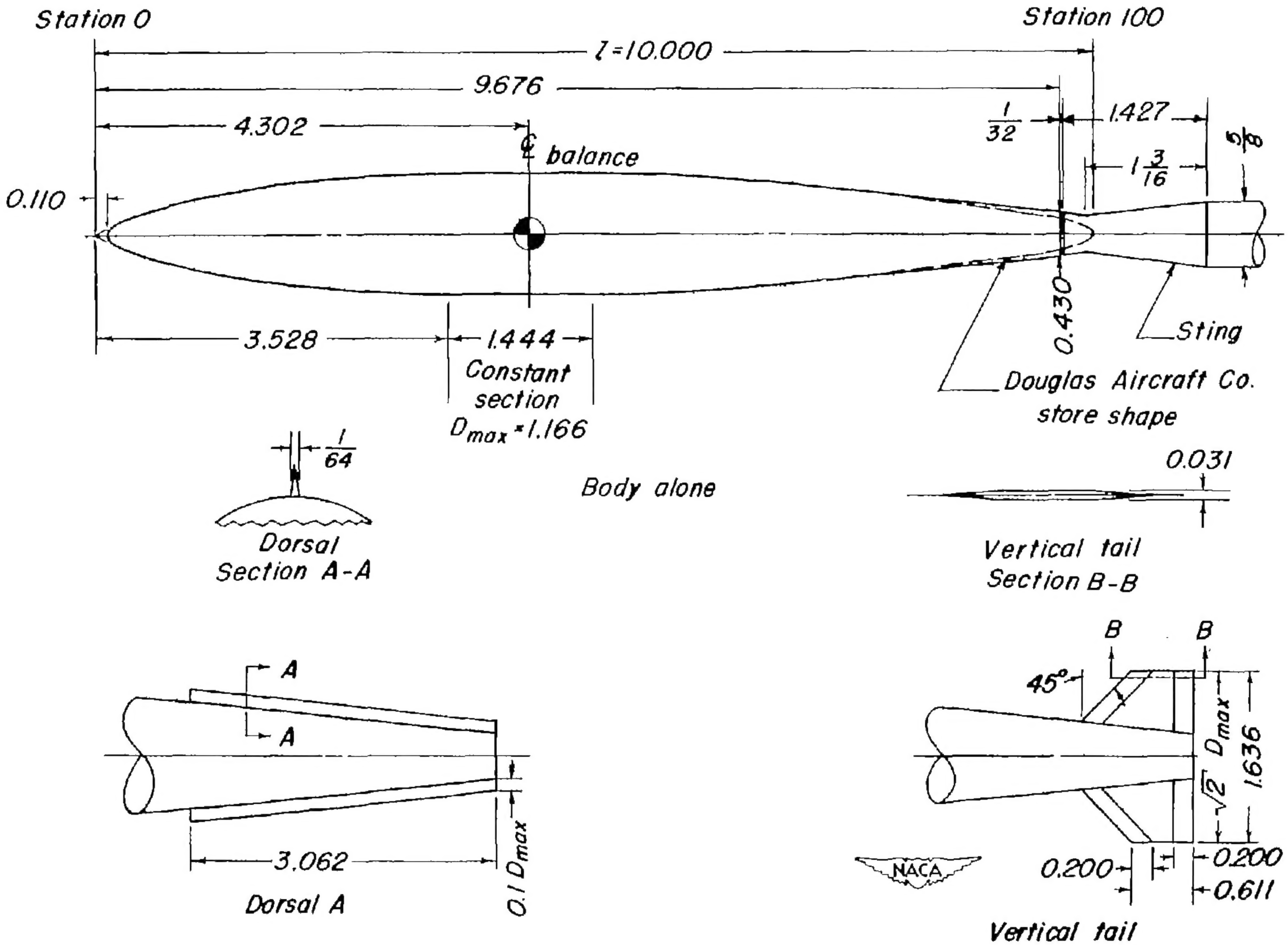

Figure 1.- Drawings of the configurations investigated. All dimensions are in inches.

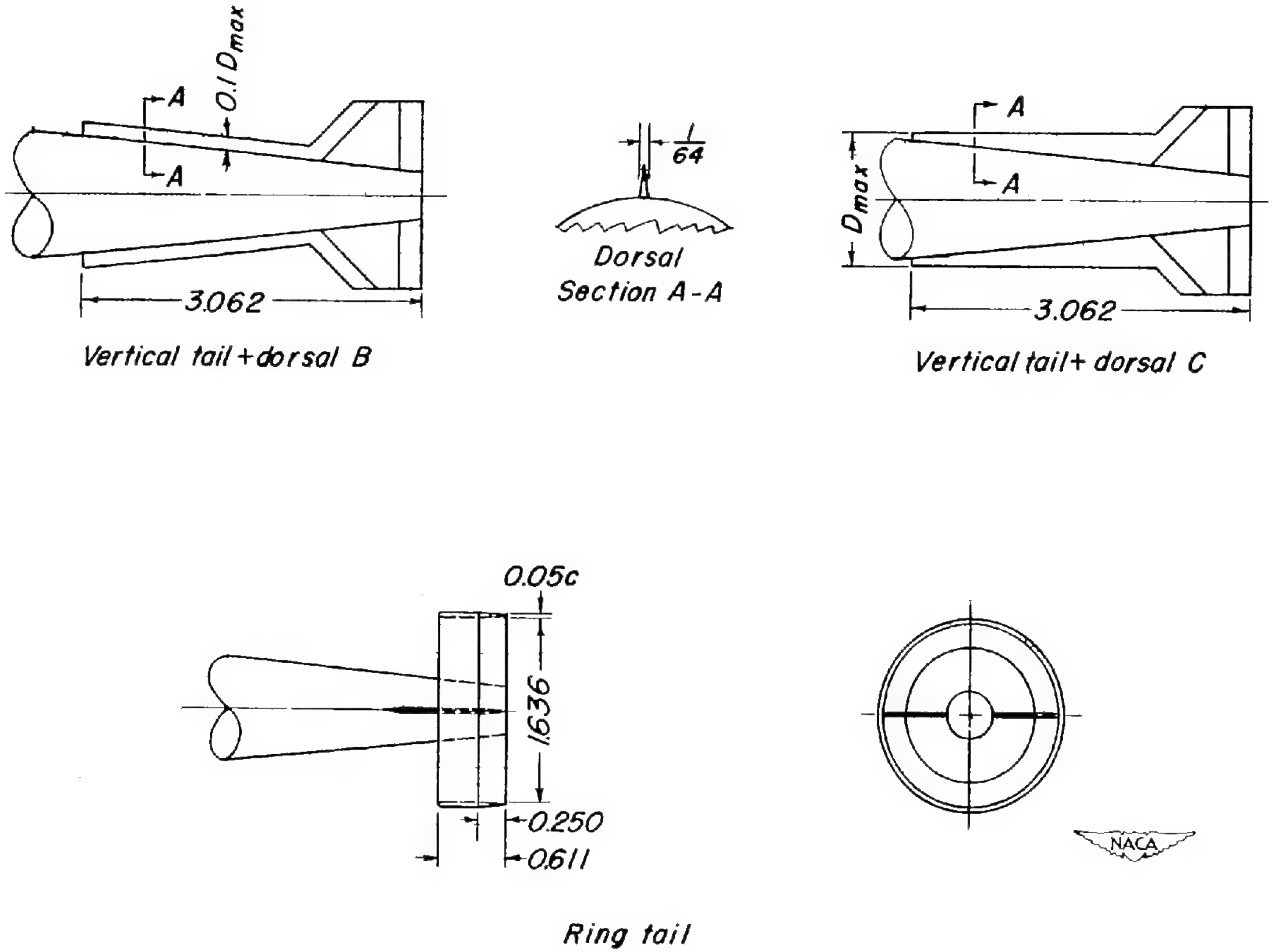

Figure 1.- Concluded.

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Figure 2.- The sting-mounted model as tested on the transonic bump in the Langley high-speed 7- by 10-foot tunnel. Ring-tail configuration.

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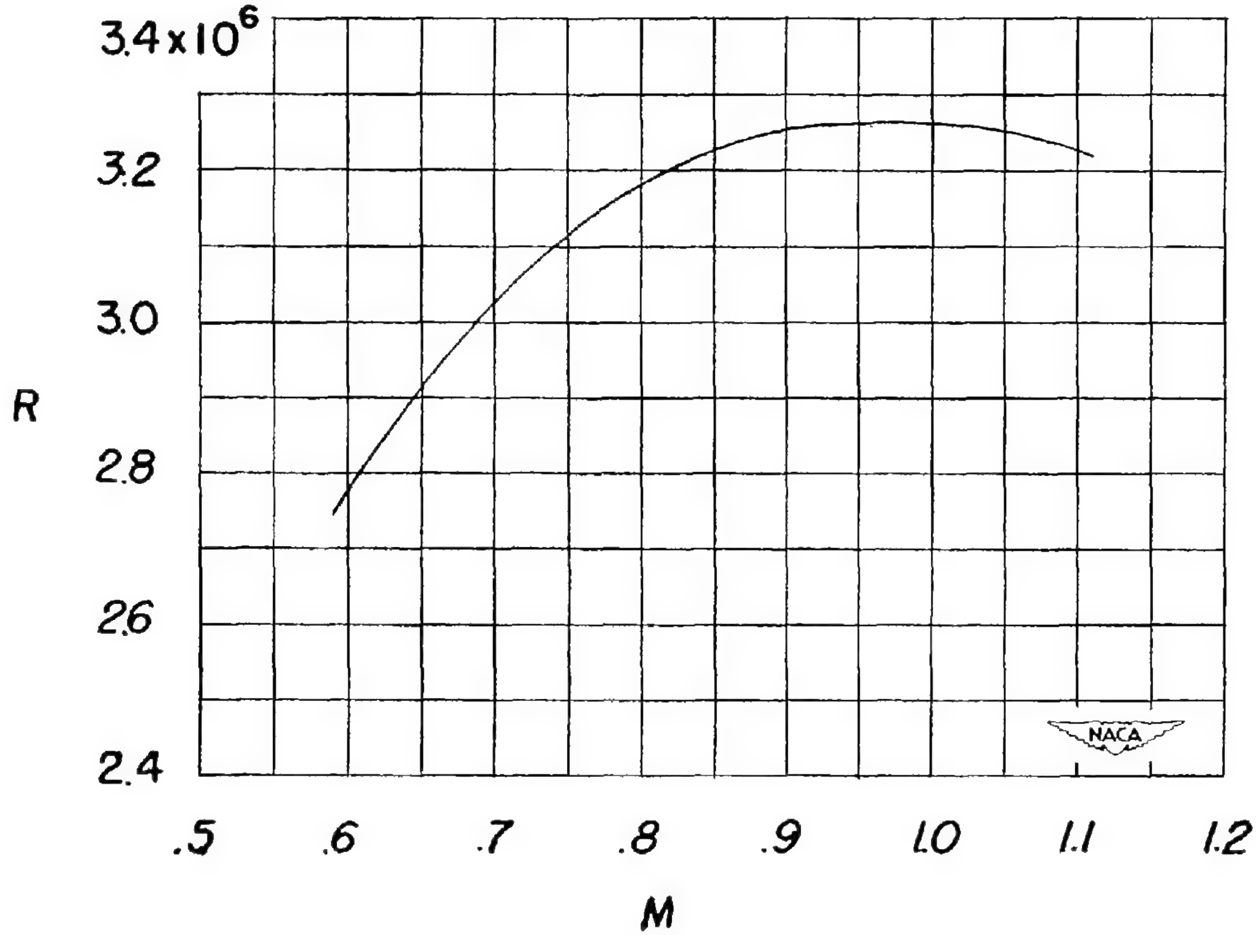

Figure 3.- Typical variation of Reynolds number with Mach number.

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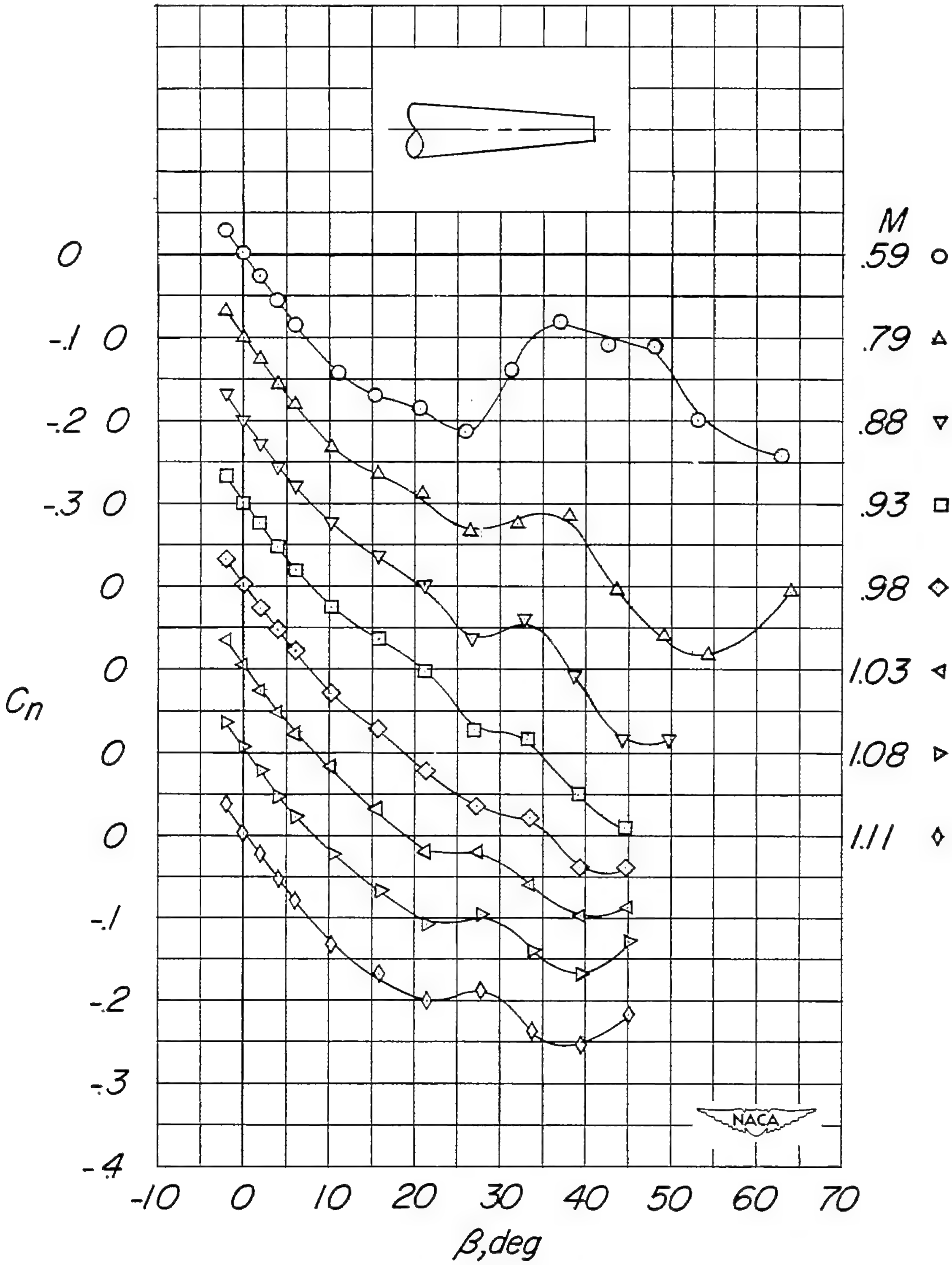


Figure 4.- Variation of yawing-moment coefficient with angle of sideslip for various Mach numbers. Body-alone configuration.

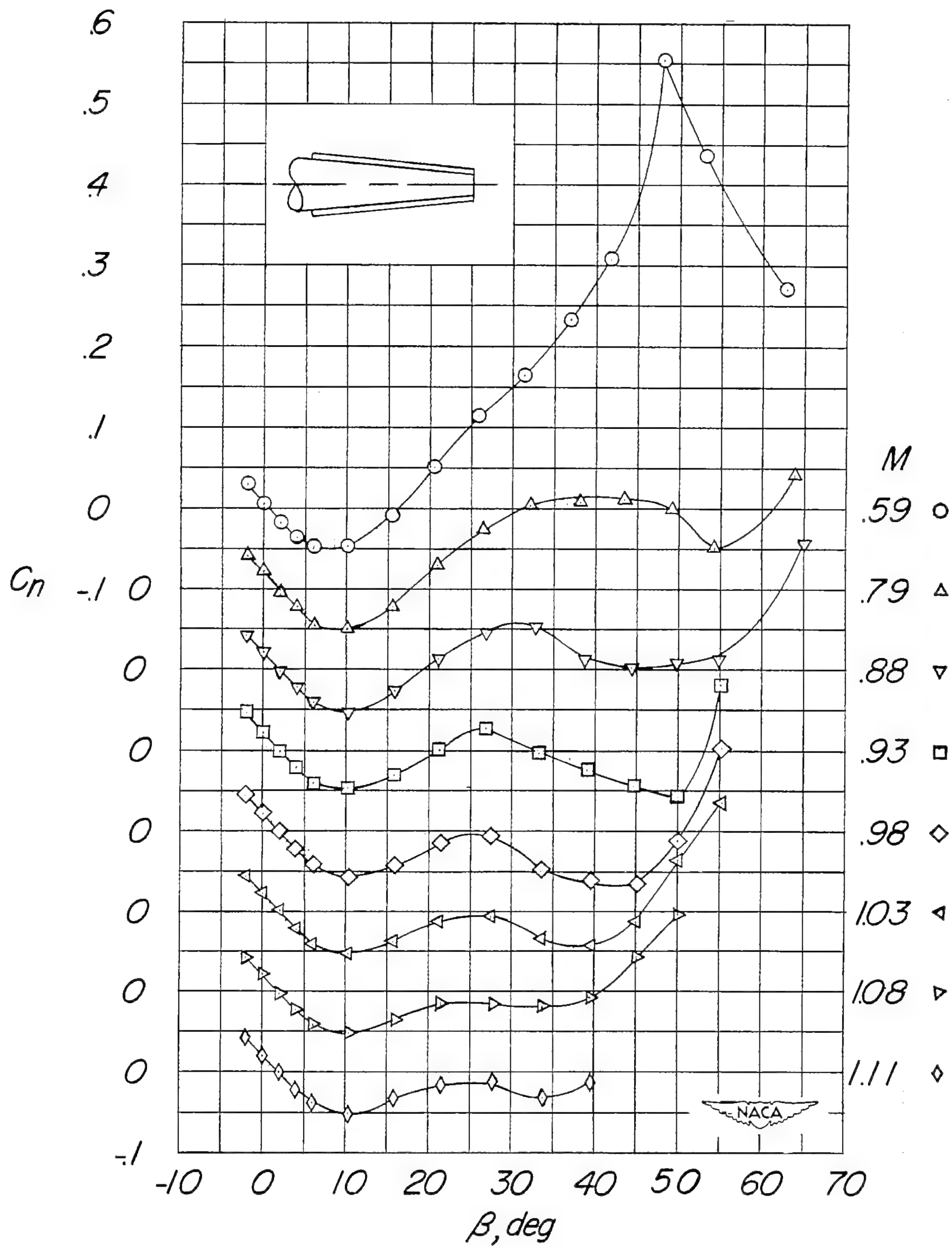


Figure 5.- Variation of yawing-moment coefficient with angle of sideslip for various Mach numbers. Body—dorsal-A configuration.

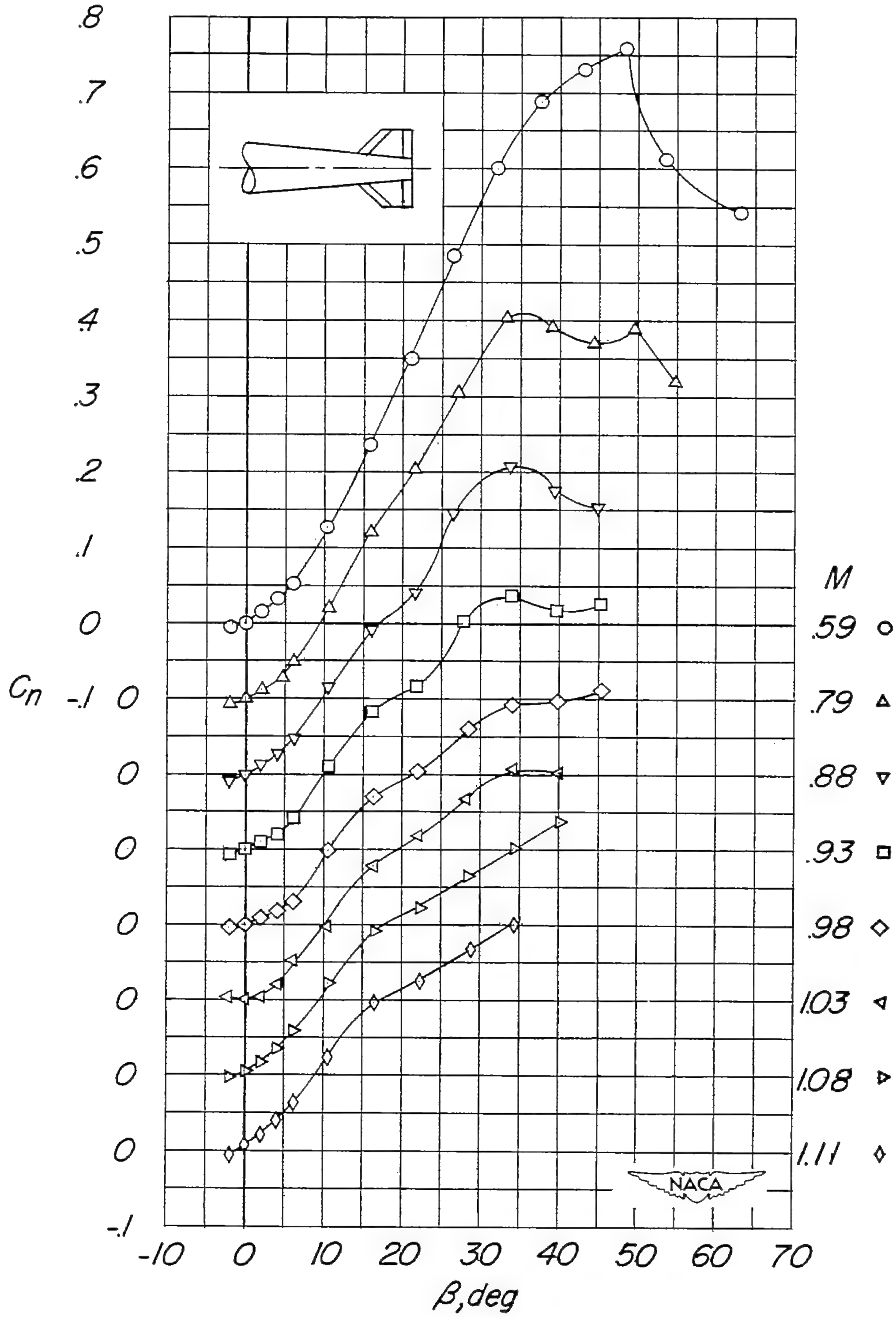


Figure 6.- Variation of yawing-moment coefficient with angle of sideslip for various Mach numbers. Body—vertical-tail configuration.

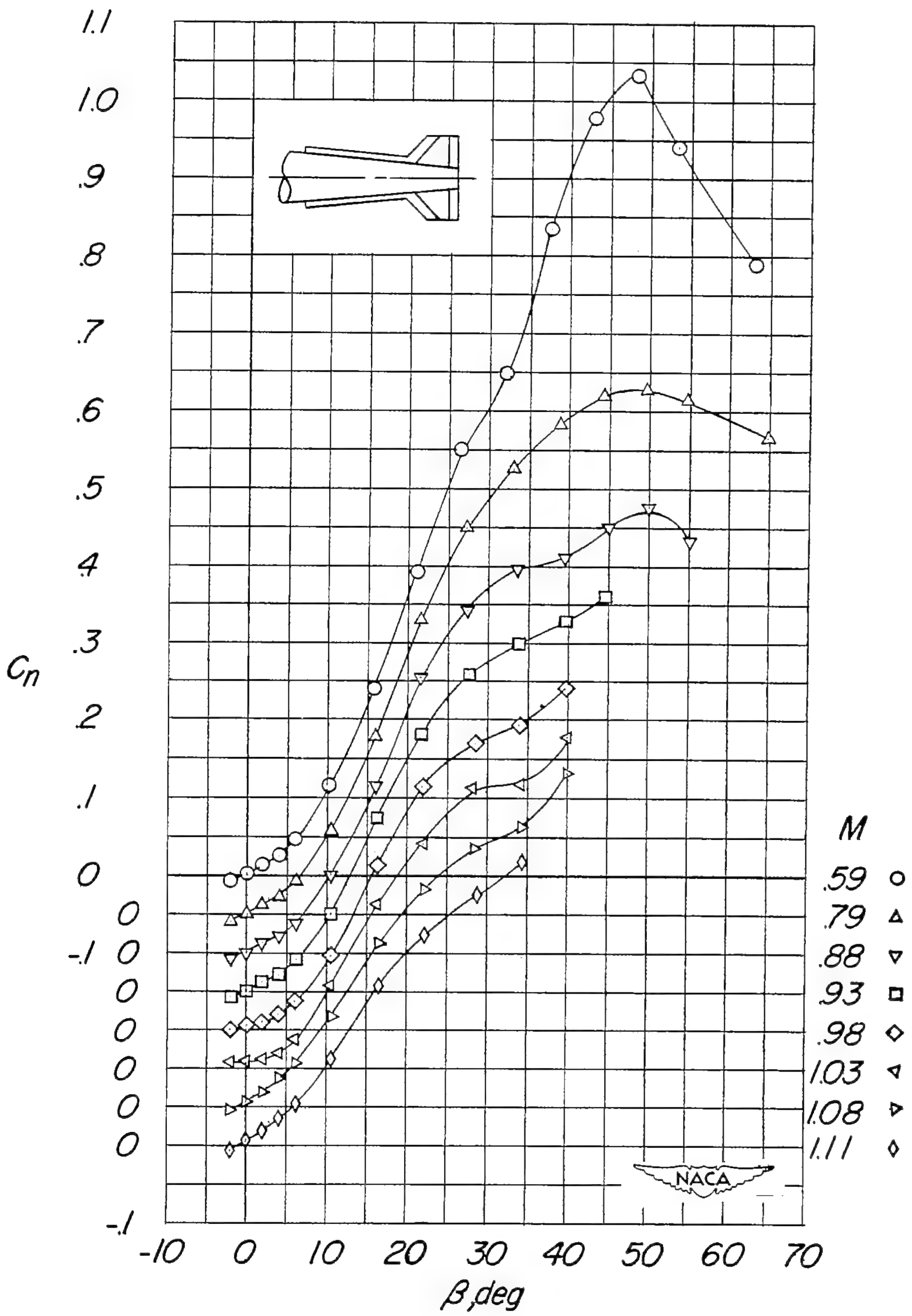


Figure 7.- Variation of yawing-moment coefficient with angle of sideslip for various Mach numbers. Body plus vertical-tail plus dorsal-B configuration.

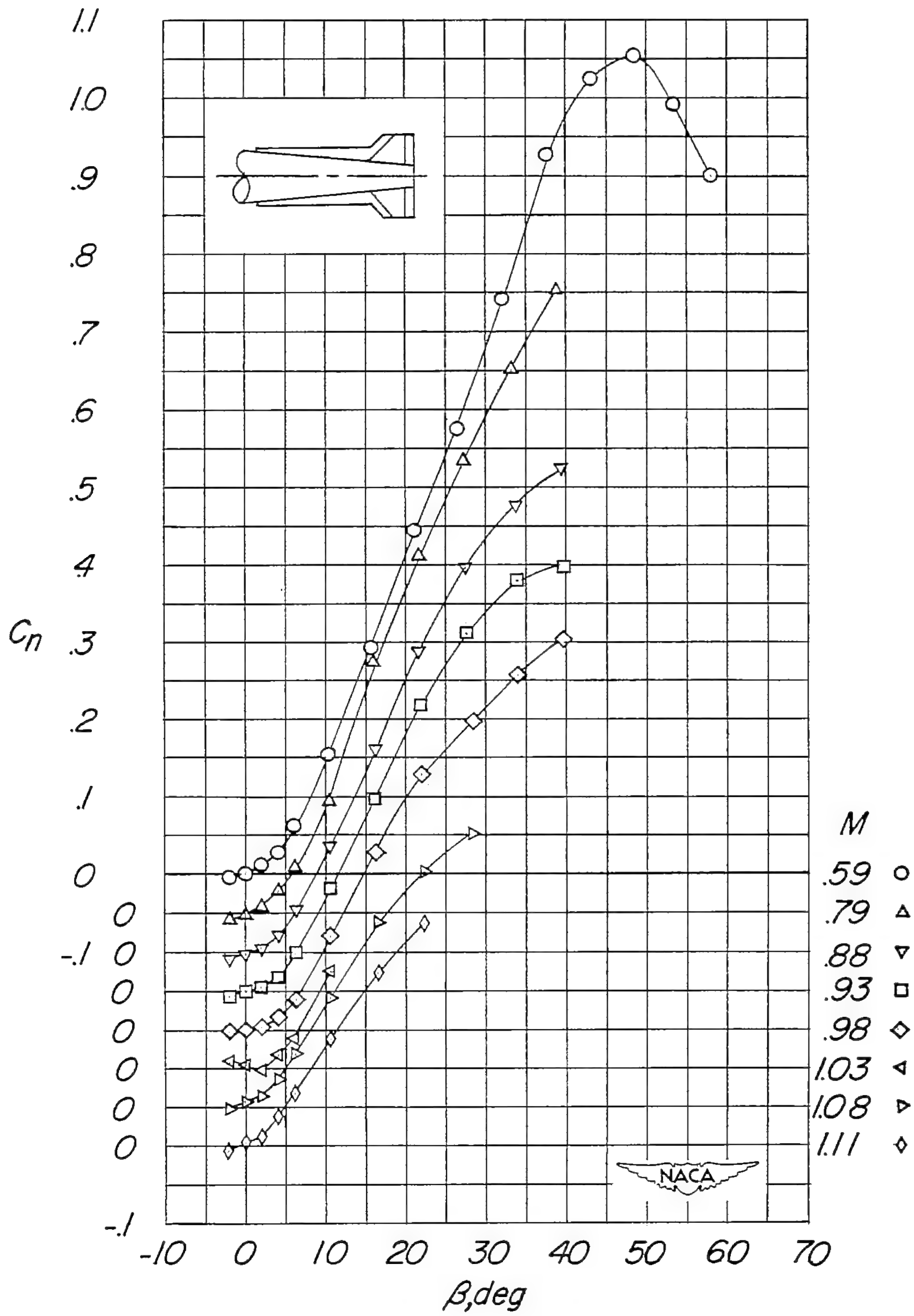


Figure 8.- Variation of yawing-moment coefficient with angle of sideslip for various Mach numbers. Body plus vertical-tail plus dorsal-C configuration.

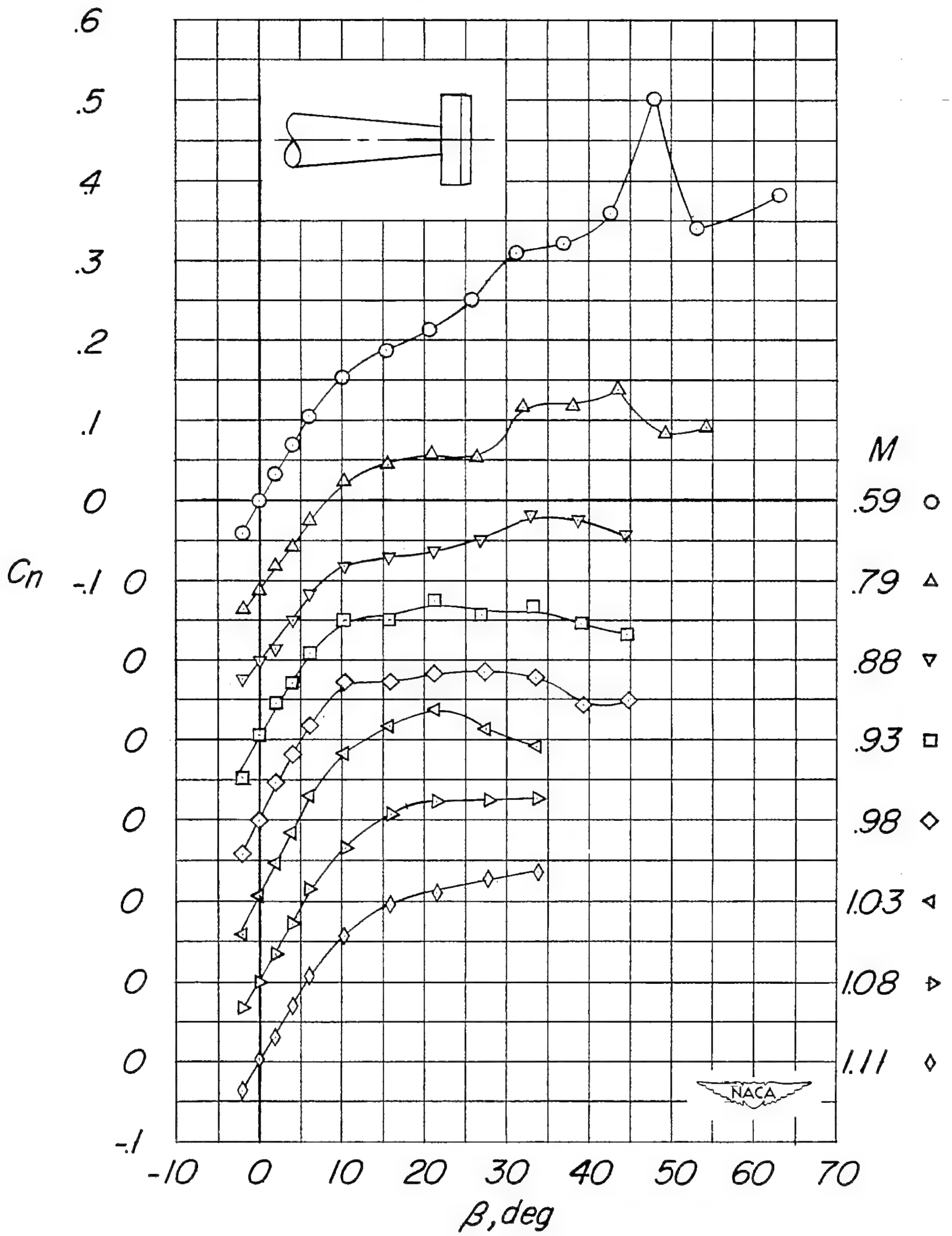


Figure 9.- Variation of yawing-moment coefficient with angle of sideslip for various Mach numbers. Body—ring-tail configuration.

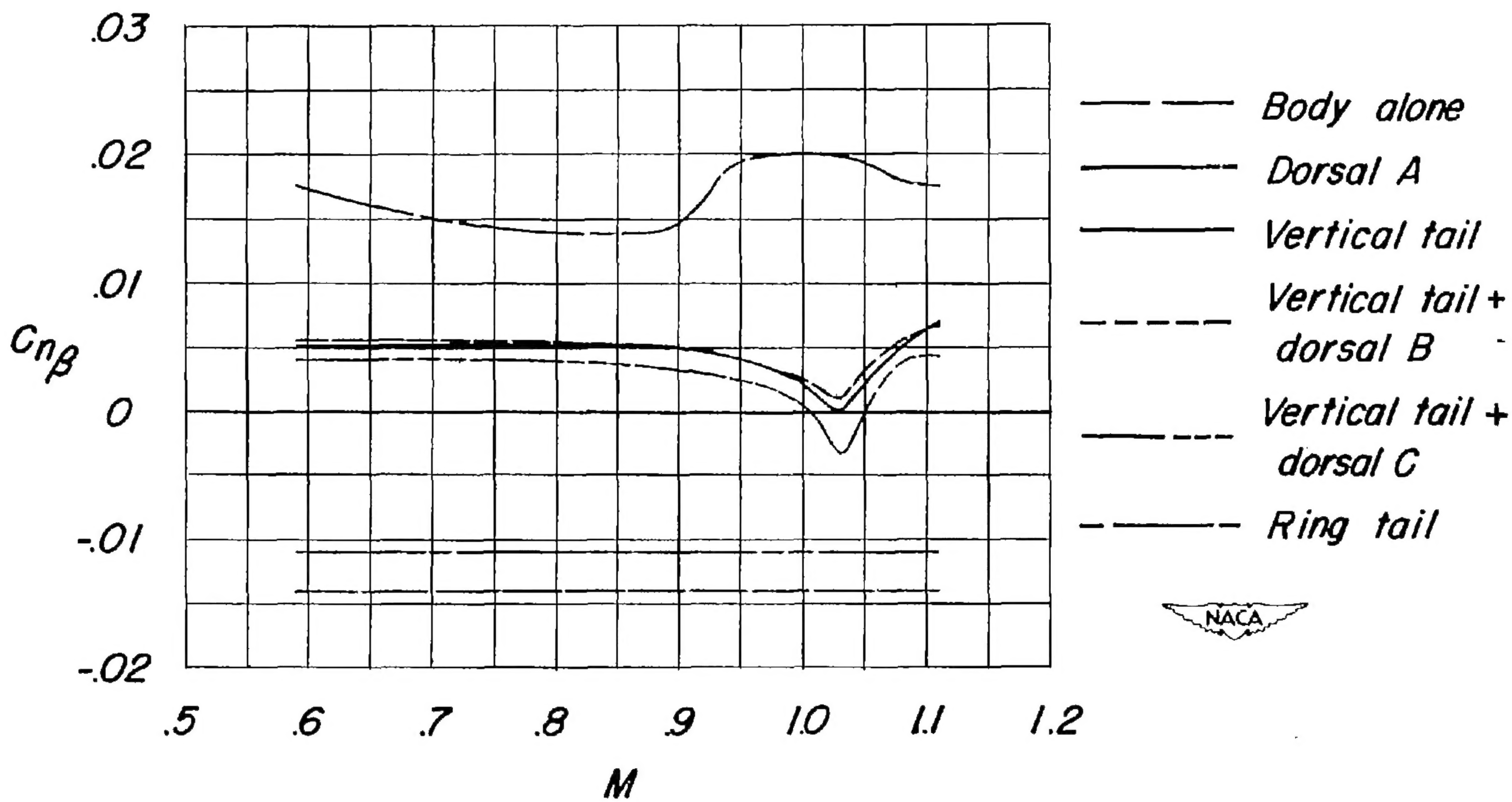
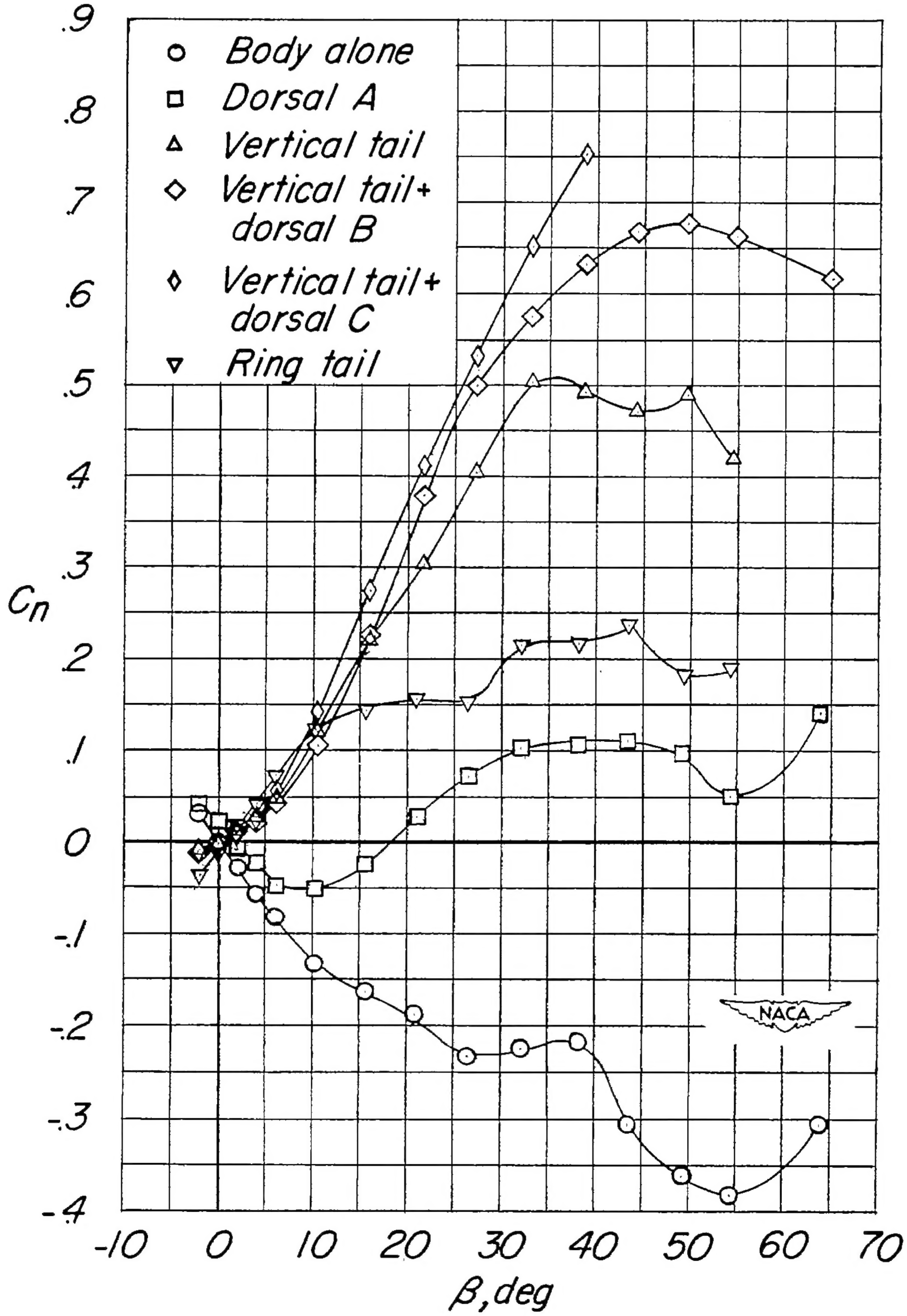
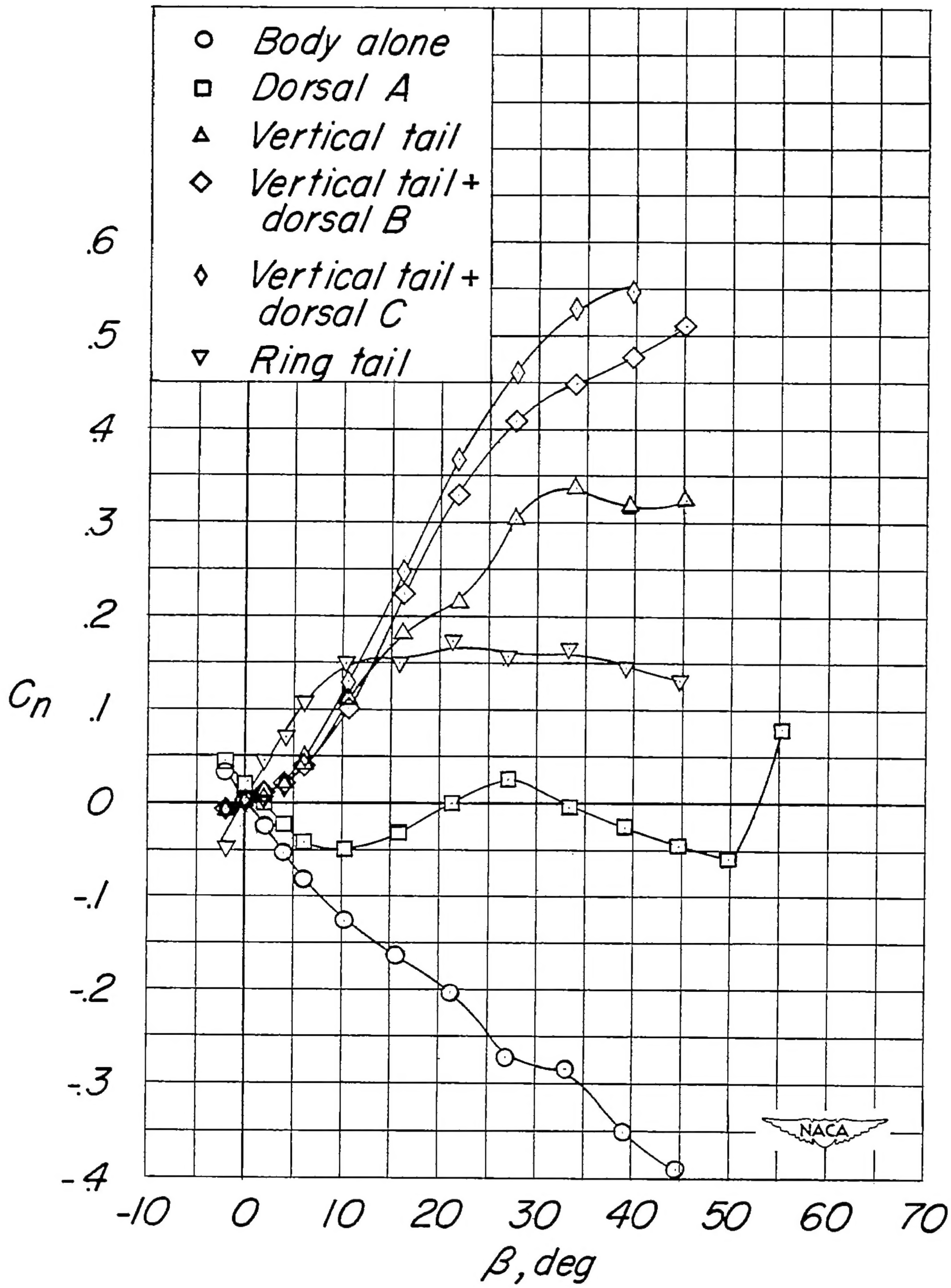


Figure 10.- Variation of C_{n_β} with Mach number for the six configurations investigated.



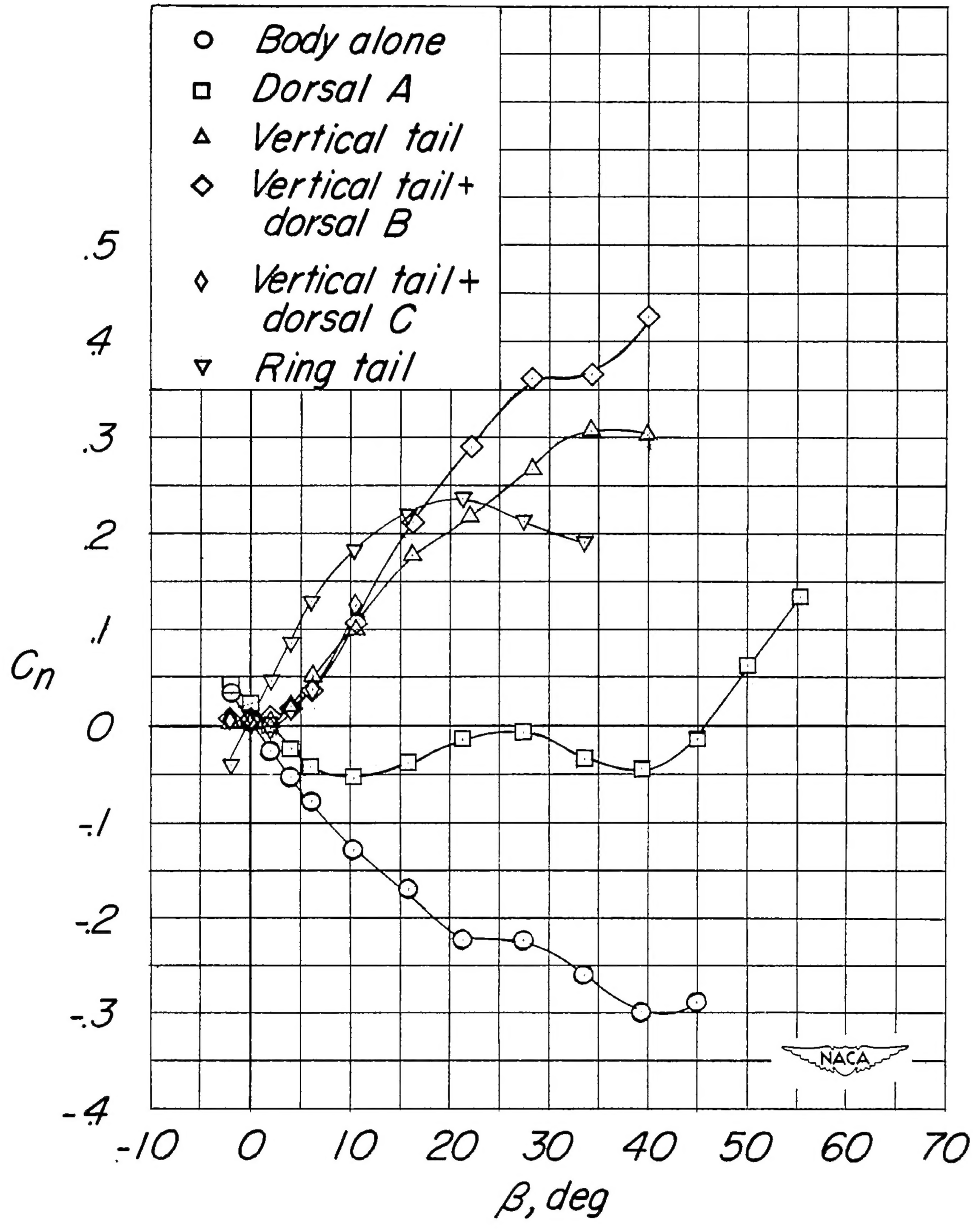
(a) M = 0.79.

Figure 11.- Effect of model configuration on the variation of yawing-moment coefficient with angle of sideslip.



(b) M = 0.93.

Figure 11.- Continued.



(c) M = 1.03.

Figure 11.- Concluded.

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